Paleopedology Comes Down to Earth

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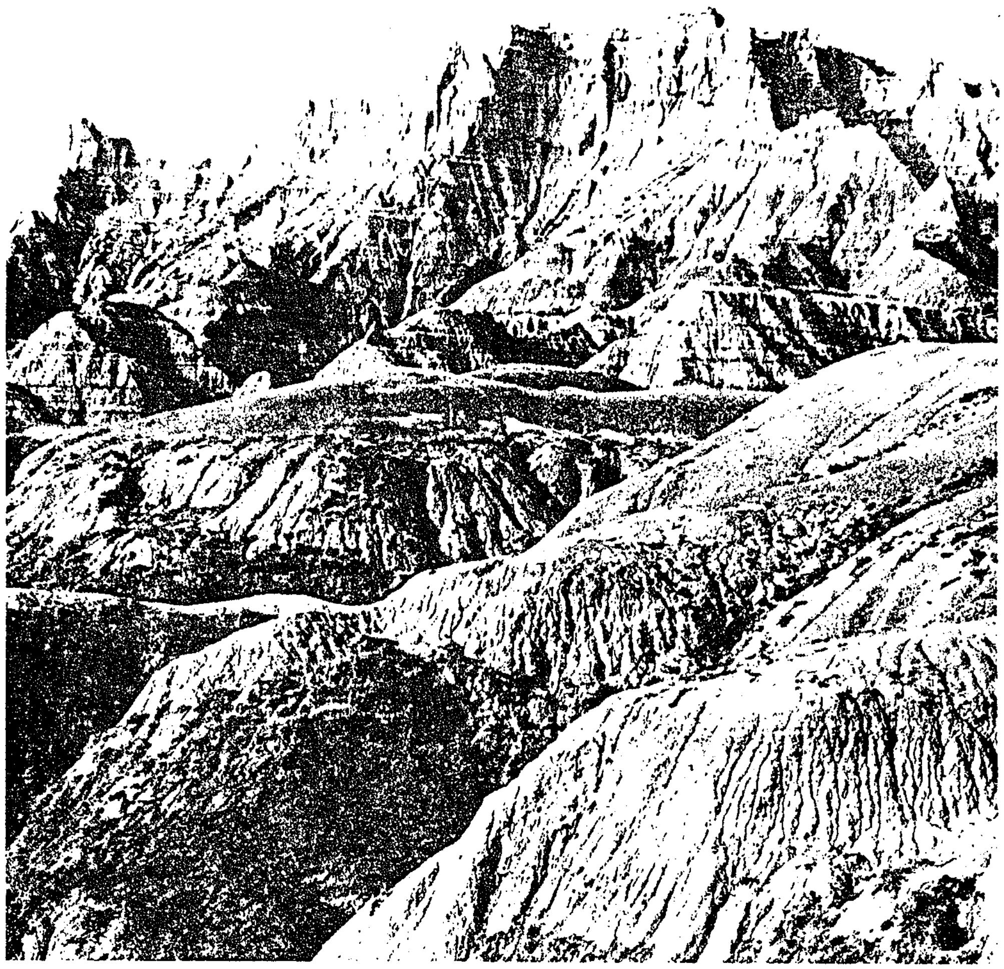

Figure 1. The Late Eocene to Oligocene White River and Arikaree Groups in the Pinnacles area of Badlands National Park (South Dakota) have long been regarded as the deposits of rivers and floodplains. The subtle and scenic color-banding of this and many similar sedimentary successions are now known to be largely the result of ancient soil formation. This sequence contains 87 superimposed fossil soils (including the one developed on the unconformity with Late Cretaceous marine rocks in the foreground) within a stratigraphic thickness of 143 m. (See Retallack, 1983)

Abstract

One of the signs that an infant discipline is finding its feet, is that it is being taught, not merely discussed or researched. In this essay, I present my curriculum for a new course in paleopedology (the study of fossil soils) for college geology seniors. It is too early yet to define paleopedology's scope, central concepts, relationships to other disciplines and methodology. My course explored interpretation of ancient terrestrial environments from fossil soils and study of the fossil record of soils as an additional approach to earth history. Paleopedology may eventually become a respectable, even dogmatic, subdiscipline of the earth sciences, but in these early days, it is still a delightful intellectual adventure.

Key words: Course descriptions; geology teaching; stratigraphy, historical geology, paleoecology; surficial geology — soils.

Journal of Geological Education, 1983, v. 31, p. 390

Paleopedology

Paleopedology, hmmmm...... No, it has nothing to do with studying the health of Sumerian schoolchildren from their clay tablets. It is not from the ancient Greek, "pais," "paidos," from which pediatrician is derived. Nor is it concerned with the corns and ingrown toenails of ancient Egyptian mummies. It is not from the Latin, "pes," "pedis," from which pedestrian is derived. Paleopedology is the study of fossil soils, and is derived from an ancient Greek word ("pedon," "pedou") for ground. It can be regarded as an extension of pedology (soil science), but it is not an aspect of that science compatible with the usual orientation of pedology towards crop production or land planning (Nikiforoff, 1943). While paleopedology may offer an important historical perspective on pedogenesis (the origin of soils and soil features), it can also be considered an additional way of approaching historical geology.

Soils, like organisms, sediments and tectonic processes on earth, have evolved over the past 4.5 billion years. Although little is currently known about the fossil record of soils, it is a promising new source of evidence for changes in terrestrial paleoenvironments. Paleopedological studies can have important ramifications for historical aspects of paleobotany, vertebrate paleontology, paleoanthropology and archaeology (Retallack, 1981). Although soil formation is the conceptual antithesis of sedimentation, fossil soils may also provide evidence on factors and rates of processes operating in "sedimentary" systems — the conventional domain of sedimentology. Paleopedology is just beginning to nudge its way into the throng of geological disciplines. Its scope and relationships to them remain to be defined.

Course Description

During the fall term of 1982, I had an opportunity to teach my first course in paleopedology to college geology majors at the senior level. As is often the case, I am sure that I learned more than the students. Teaching a course in a little-explored area of science can force one to introduce order and clarity not formerly perceived to a body of knowledge. The course outline discussed in the following paragraphs is close to, but not exactly the same as that taught. Rather, it represents the way I would teach paleopedology the *next* time.

The course included lectures, laboratory exercises, field excursions and a term report. It was worth three credit points, although four might reflect more accurately the amount of work done. (My students would prefer five.) About two-thirds of the course material was covered adequately in the textbook by Peter Birkeland (1974). His book was supplemented by published papers. Soil Survey Staff (1975), Brewer (1976) and Buol and others (1980) proved invaluable references.

The first group of lectures dealt with the nature and occurrence of soils and fossil soils. This was loosely patterned after conventional courses in soil science, but with emphasis on features observable in fossil soils. Root traces, soil horizons, soil structure and soil micromorphology were stressed as features by which fossil soils can be distinguished from enclosing sedimentary rocks. The soil-forming processes discussed were largely those evident in fossil soils, such as fire (from charcoal and stone weathering), clay heave (from gilgai structure), acid-base reactions (or pH from carbonate and evaporite mineral content), oxidation-reduction reactions (or Eh from organic matter content and oxidation state of iron minerals) and bioturbation (from burrows and root traces). None of the classifications of modern soils are completely satisfactory for application to fossil soils. The United States Department of Agriculture classification (Soil Survey Staff, 1975) was used because it is widely accepted, not only as a classification but as the language of soil scientists. A consideration of the special problems of studying fossil soils at major geological unconformities, in Quaternary alluvium and in thick sedimentary successions, was an opportunity to discuss stratigraphic versus paleoenvironmental interpretation and naming of fossil soils. Late diagenetic alteration of fossil soils after burial is another important consideration. Particularly troublesome diagenetic changes include reddening of ferric oxide minerals, burial gleization, potassium metasomatism of clay minerals, silicification, compaction, and copper, vanadium and uranium mineralization.

A second group of lectures was organized around the soil-forming factors of Hans Jenny (1941) — climate, organisms, topographic relief, parent material and time for formation. Studies of the formation of modern soils and soil features provide analogs by which the action of these factors in the past can be interpreted from fossil soils. In a similar manner, past sedimentary environments and processes are reconstructed from sedimentary structures, and extinct animals from fossil bones. As examples from paleopedology, calcic horizons form in soils of subhumid to semiarid climates and the depth to the top of the calcic horizon within the profile is a guide to mean annual precipitation. Thick and continuous eluvial (A2) horizons, associated with large root traces are an indication of closed-canopy woodland or forest vegetation. Horizons of siderite nodules, sphaerosiderite or pyrite framboids, which can be demonstrated to be original parts of the soil, form in waterlogged soils of low-lying parts of the landscape. Very different kinds of fossil soils are often found on different parent materials, such as granite and peridotite, along geological unconformities. Sedimentary relicts, such as bedding and ripple marks, are progressively obliterated from soils formed on alluvium with increased time of soil formation.

A third and final group of lectures concerned major events in the evolution of soils on earth. The strikingly different processes of soil formation on the moon (Lindsay, 1976) provided another opportunity to discuss the different definitions of soil used in agronomy, geology, engineering and astronomy. Lunar, Martian and Venusian soils provide some insights into the possible nature of soils on earth before the sedimentary rock record (before about 3700 million years), as well as into differences among planets of the solar system. The remaining lectures dealt with the evidence of fossil soils on the nature of Precambrian atmospheres, on the origin of soil microbiota, on the early Paleozoic origin of vascular land plants, on the mid-Paleozoic advent of forests, on the mid-Tertiary spread of grasslands and on late-Cenozoic human evolution. This part of the course introduced an historical perspective on pedogenesis and the evolution of soils and soil features. Since there is presently little paleopedological evidence for many of these events, much of this part of the course involved erecting and comparing hypotheses and appropriate research projects. Considering possible applications of paleopedology in this way strengthened understanding of concepts and terminology developed earlier in the course, and also encouraged much stimulating speculation.

Laboratory

Laboratory sessions involved reading and assimilating several pages of text and diagrams, then using this and other information to answer specific questions about hand specimens, thin sections, color photographs or chemical analyses of fossil soils. The first laboratory was devoted to the examination of hand specimens of fossil root traces of various kinds, and the second to hand specimens of peds, cutans, pedotubules and other soil features. A laboratory session on soil micromorphology stressing Brewer's (1976) terminology, assumed familiarity with optical mineralogy. This should be mastered before the laboratory session on soil horizons because petrographic thin sections, as well as hand specimens, and field photographs are needed to effectively identify horizons in fossil soils. Once this is done, the paleosol can also be identified, as an introduction to the United States Department of Agriculture classification (Soil Survey Staff, 1975).

A laboratory session on late-diagenetic alteration of fossil soils stressed changes after burial which may substantially influence interpretation of their paleoenvironment or original nature. Because the late-diagenetic effects were considered after the main features of fossil soils, it is important that the materials examined in previous laboratory sessions not be affected by severe late-diagenetic alteration.

A laboratory session on geochemical analyses of fossil soils introduced techniques of number-crunching (normalizing major oxide percentages to a weight per unit volume of a stable constituent, and calculating molecular, also molar, weathering ratios). Graphs of the results of both manipulations of chemical data are more easily interpreted than tabulated analyses.

The preservation of fossils in fossil soils depends on the chemical nature of the soil and fossil, on the time over which the soil formed and on the kind of ecosystem it supported. These factors were considered in an analysis of fossil occurrences in a long stratigraphic section including numerous fossil soils. Common styles of preservation of fossils in fossil soils were also considered in this laboratory session.

The remaining three laboratory sessions dealt with traditional geological topics, but from a pedological perspective. A laboratory on fossil soils of coal measures introduced the United States Department of Agriculture (Soil Survey Staff, 1975) classification of organic horizons and of waterlogged soils of wetlands. A laboratory on fossil soils of calcareous red beds similarly presented soil classification and soil forming factors in arid lands. In both these exercises, specific fossil soils were labelled, identified and interpreted from color photographs, columnar sections, hand specimens and petrographic thin sections. A final laboratory session on very strongly developed fossil soils of major geological unconformities dealt with problems in the interpretation of bauxites and laterites. As additional materials become available, I hope to extend this laboratory session to include silcretes and calcretes.

Field Work

Geology majors often have little experience with soils, so it is important to show them modern soils and soil features in the field. Near Eugene, Oregon, Mollisols and Alfisols can be seen within a half day excursion from campus. The mollic epipedon and well-differentiated A and B horizons are two important features of soils which are better experienced than explained. A class project was generated from a two-day excursion to examine fossil soils in an Eocene-Oligocene alluvial sequence in central Oregon. After an introductory tour of the geology and paleontology of the area, each student excavated and described a fossil soil and collected representative specimens. The project included a review of published work on the geology and paleontology of the area, and description and identification of the fossil soils according to the conventions of the United States Department of Agriculture (Soil and Survey Staff, 1975). Also required was an account of what could be inferred about the former climate, organisms, topographic relief, parent material and time of formation of the fossil soils, and an assessment of how this corresponds with existing ideas about the paleoenvironment of these rocks. Also suitable for such a project would be numerous variegated and red beds of Tertiary age, exposed as scenic badlands throughout the western United States (Figure 1). In the midwest, Pennsylvanian rocks would be a more convenient local source of fossil soils. These are also common in several Paleozoic red beds of the Appalachians and in early Cretaceous rocks of the region around Washington, D.C.

By the time the last laboratory exercises and the project were completed, students were noticeably more comfortable with the terminology and concepts of soil science, and aware of the different viewpoints of paleopedology and sedimentology. Features of rocks which formerly seemed of little significance, such as iron stains or calcareous nodules, were often of great importance to the full interpretation of fossil soils. The different perspective also allowed a re-examination of the factors involved in the major changes in rock facies and fossil assemblages during the history of the earth. These issues provided a stimulating source of discussion.

Conclusion

Paleopedology will undoubtedly grow to become a respectable, even dogmatic, subdiscipline of earth sciences. In these early days, while we are still seeking to identify its scope, central concepts, relationship with other disciplines and methodology, it is a delightful intellectual adventure.

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About the Author

Gregory J. Retallack received a B.Sc. Hons. in 1974 and a Ph.D. in 1978 for his studies in geology at the University of New England, Armidale, N.S.W., Australia. He taught for one year at Northern Illinois University, Dekalb, and was a Visiting Scientist at Indiana University, Bloomington, for three years. Since 1981, he has been Assistant Professor at the University of Oregon, Eugene. Dr. Retallack's thesis research on Triassic sediments, fossil soils and fossil plants near Sydney, Australia, was recognized by the award of a University Medal from the University of New England. For his published account of these Triassic soils he gained the Stillwell Award and Medal of the Geological Society of Australia. Dr. Retallack's current research interests include studies of fossil soils relevant to the appearance of savanna and prairie vegetation in Oligocene alluvium of Badlands National Park, South Dakota. He is also working on paleoenvironments of fossil hominoids in the Miocene outwash of the Himalaya, Karakorum and Hindu Kush Mountains of northern Pakistan.